PRRC 94-50

Quarterly Technical Progress Report

IMPROVED EFFICIENCY OF MISCIBLE CO_2 FLOODS AND ENHANCED PROSPECTS FOR CO_2 FLOODING HETEROGENEOUS RESERVOIRS

DOE Contract No. DE-FG22-94BC14977

New Mexico Petroleum Recovery Research Center
New Mexico Institute of Mining and Technology
Socorro, NM 87801
(505) 835-5142

Contract Date:	April 14, 1994
Anticipated Completion Date:	April 13, 1997
DOE Award for FY 1994:	$320,000

Program Manager:	F. David Martin
Principal Investigators:	Reid B. Grigg John P. Heller David S. Schechter

Contracting Officer's Representative:	Jerry Casteel Bartlesville Project Office

Reporting Period:	July 1, 1994 - September 30, 1994

US/DOE Patent Clearance is <u>not</u> required prior to the publication of this document.

OBJECTIVES

The objective of this work is to improve the effectiveness of CO_2 flooding in heterogeneous reservoirs. Our intent is to investigate new concepts that can be applied by field operators within the next two to five years. Activities will consist of experimental research in three closely related areas: 1) further exploration of the applicability of selective mobility reduction (SMR) in the use of foam flooding, 2) possible higher economic viability of floods at slightly reduced CO_2 injection pressures, and 3) taking advantage of gravitational forces during low IFT, CO_2 flooding in tight, vertically fractured reservoirs.

Task 1 of this project is based on work performed during the recent "Field Verification of CO_2-Foam" (DOE/MC26031) and on a previous project, "Improvement of CO_2 Flood Performance" (DOE/MC21136). In those research projects, as well as in projects reported by other researchers, we have found evidence for SMR when using certain surfactants in mobility experiments in which CO_2 and surfactant solution were pumped simultaneously through core samples cut from rocks of different permeabilities. Experiments that would decisively define the conditions under which SMR could be reliably realized in CO_2 floods could increase present productivity and add millions of barrels to the reserves of many oil fields in the Permian Basin, and elsewhere that CO_2 is available.

The objective of Task 2 of the project is to demonstrate the feasibility of decreasing CO_2 requirements for CO_2 flooding. This objective can be achieved by using one or both of two approaches. First, at a constant temperature, the density of CO_2 decreases with decreasing pressure, thus achieving reservoir fill volume with less mass at a lower pressure. The density of CO_2 is always less at the minimum miscibility pressure than at several hundred pounds pressure higher where most systems are being flooded. The density difference can be as high as fifty percent. Thus, how can we take advantage of this fact? Second, foaming agents can be used in conjunction with the injection scheme of water alternating with carbon dioxide as a mobility control agent. Using these two concepts together should provide a synergistic effect by greatly reducing CO_2 requirements while maintaining or increasing the sweep efficiency of the process. This concept should be particularly applicable in the New Mexico-Texas region where many of the present and potential reservoirs for CO_2 miscible flooding are located. The concept should also be applicable to any gas injection scheme. All the experimental tests and modeling work in this study are designed to increase our understanding and to test concepts related to this process.

Task 3 of the project falls under the broad topic, "Low IFT Processes," and is directly related to all EOR techniques that rely on reduction of interfacial tension for mobilization of residual oil. Miscible or near-miscible oil recovery processes, whether surfactant flooding or gas injection processes near the MMP, ultimately depend on reduction of interfacial tension between the resident and injected fluids. The approach to miscibility from an initially immiscible situation involves important consequences regarding dynamic lowering of the IFTs and subsequent alteration of the capillary pressure, P_c, and the Leverett J-function. These important parameters, in turn, determine the relative permeability function used for reservoir simulation.

Knowledge of the mechanism of IFT lowering is important for simulation of EOR processes. For instance, the Parachor Method is currently used as a prediction tool of IFT in multicomponent mixtures. The accuracy of the Parachor Method is limited and has been the subject of criticism, although there has been no rigorous study demonstrating the success or failure of the Parachor Method under widely differing conditions. The IFT and the density difference between the phases as miscibility is approached are the measured parameters in evaluation of the parachor. IFT vs. density difference is also crucial in evaluating capillary-gravity equilibrium in fractured reservoirs, yet there is little understanding of the theory behind the Parachor Method and almost no literature concerning measurement of low IFT CO_2/crude oil mixtures. We hope to refine the use of the Parachor Method and apply the results to the prediction of measured IFTs of crude oil/CO_2 mixtures using only an equation of state (EOS), and ultimately, correlate IFTs with the MMP of selected oils. A supplementary, but equally valuable task to the proposed research, will be the creation of a CO_2/crude oil database, which will eventually be necessary for future CO_2 floods. The following plan is a list of activities for Task 3: 1) Design a pendant drop apparatus for measuring IFTs (oil/water, oil/gas, gas/water) under a wide range of reservoir conditions; 2) analyze the ability of flash routines to predict liquid and vapor densities for calculation of IFTs (Parachor Method) of near miscible, multicomponent mixtures (CO_2/oil, N_2/oil, gas condensate); and 3) correlate IFT and minimum miscibility pressure (MMP) in simple systems and crude oils from measured IFTs (pendant drop) and slim tube experiments.

SUMMARY OF TECHNICAL PROGRESS

TASK 1 — SMR STUDY IN CO_2 FOAM

Progress in Search for Applicability of SMR in CO_2 Foam

In order to efficiently screen surfactants to assess their potential for selective mobility reduction (SMR), we modified our standard high-pressure mobility experiment to speed up the measurements of the mobility of CO_2 foam through rock samples with different permeability. In our new modified experiment, two coreholders were assembled in a series in the path of the CO_2-foam such that the pressure across each of them could be measured at the same time. The total volumetric flow rate of CO_2

foam was maintained constant during the experiment by withdrawing the output fluid with another Ruska pump downstream. In this way, the same flow rate of CO_2 foam through each core at steady state was assured, and the mobilities in high and low permeability rock samples were determined simultaneously.

To check the validity of this new design in mobility measurement, we first conducted a few experiments to study the effect of core position to the mobility measurement. Baker dolomite and fired Berea sandstone were used in these tests with Chevron surfactant Chaser CD1050.® Our preliminary results showed that there is no significant effect of the core position by interchanging the position of the core in the flow path on the mobilities of either CO_2 surfactant-free brine or CO_2 foam.

Mobility measurements of CO_2 foam were then continued to investigate the effect of surfactant type, concentration, and rock type, as well as the rock's permeability to the SMR of CO_2 foam. Chevron's surfactant Chasers CD1045 and CD105, and rock samples cut from Baker dolomite and Berea sandstone were used in the test. Two surfactant concentrations, 500 ppm (near or below the critical micelle concentration of each surfactant) and 1000 ppm (above the surfactants' CMC) were used to generate the foam. All tests were conducted at 101°F and 2100 psi.

Chaser CD1050 was one of the surfactants previously identified to show considerable SMR in a carbonate reservoir rock (EVGSAU) when the standard high-pressure mobility experiment was conducted. In the tests with the quarry rocks using our modified design, the SMR was also observed using Baker dolomite rock samples (permeability ranging from 30 md to 110 md) and the fired Berea sandstone (permeability ranging from 130 md to 900 md). The SMR as observed in the Berea sandstone, however, is less favorable than that in the Baker dolomite. On the other hand, surfactant CD1045 exhibits slightly more favorable SMR in Berea sandstone than that in Baker dolomite. Overall, surfactant CD1050 shows a better SMR in Baker dolomite rock samples, while surfactant CD1045 exhibits a better SMR in Berea sandstone rock samples. All the results suggest that lithology of rock affects the foam behavior and its SMR to some extent. In addition to this, our results also reveal that a better SMR is exhibited at low flow velocity of CO_2-foam (4.7 ft/day) than at high flow velocity (9.4 ft/day) in all tests.

Currently, we are testing the aforementioned surfactants with the EVGSAU (carbonate) reservoir rocks. Since these reservoir rocks are preserved rock samples, the existence of residual oil is likely to affect the surfactant's property and the foam behavior. By using our modified high-pressure mobility experiment, we may quickly reconfirm or deny our previous findings by the standard high-pressure mobility measurements. Once this experimental design is verified to be valid for mobility measurements, we will use it to screen commercially available surfactants for a better SMR observable with reservoir rock at the reservoir conditions.

Through the generosity of Dr. John Preiditis of Texaco, we have obtained a sample of carbonate outcrop rock from the San Andres formation that contains a very sharp permeability contrast. Several cores had already been cut from this sample, which made it possible to see that the surface separating high and low permeabilities was relatively plane. It was possible to cut two more core samples, the diametral planes of which were roughly coincident with the dividing surface between high and low permeabilities. The ends of the two cores, which were designated TX1 and TX2, were cut perpendicular to the axes. Both of these samples are vuggy and apparently not well connected; most of the vugs are small but a few are larger and intersect the surface. The density of the small vugs is less on the low permeability side, and greater on the other side of the dividing plane.

With the PRRC scanning minipermeameter, we measured 1089 permeabilities on each of the four faces, on a 0.025 in. square grid. These were measured over the largest possible square fields (0.8 X 0.8 inches) on the end faces. The permeabilities on the low side of this surface are mostly between 0.04 md and 2.2 md., while those on the high side lie mostly between 5 and 100 md. Fig. 1 is a grayscale permeability map, made with data obtained from core TX1 on face B. Although the dividing line between the high and low permeabilities sides is quite evident, it is also obvious that the permeabilities are far from uniform, on either high or low permeability side. This is very much in accord with other fine-scale measurements with the scanning minipermeameter that have shown large variations between closely-spaced locations on most rocks.

Because of the high permeability contrast in these rock samples, they will provide an interesting test of SMR, as well as requiring time-consuming experimental work just to achieve saturation equilibrium prior to each test. Work is underway to design the coreholder for the CO_2-foam experiments, and the end cap that will divide the exit flow from the two sides. We plan to coat the cores with thick (high viscosity) epoxy and use a heavy brass tube for pressure containment with solidified, thin epoxy filling the annulus.

TASK 2 — REDUCTION OF THE AMOUNT OF CO_2 REQUIRED IN CO_2 FLOODING

Experimental Phase Behavior Tests

In support of sensitivity studies using reservoir simulators with a foam flooding option, core flooding tests using reservoir rock are being run. The foam model has been found to be sensitive to gas and water saturations. A series of tests are in progress that are examining the effects of foam quality and flow velocity on foam formation and in particular, mobility control. Earlier tests were performed on a range of foam quality found near an injection well (Chang and Grigg, 1994). This study is examining the entire range of foam qualities that will occur in the reservoir. This additional information will provide guidelines for mobility control versus foam quality over the entire quality range.

The continuous phase equilibrium (CPE) apparatus is a dynamic system that examines composition, density, and viscosity changes in a dynamic system during continuous injection of a fluid into a reservoir oil at reservoir conditions (Lansangan and Smith, 1993). We have completed a series of tests on a Permian Basin reservoir fluid at pressures ranging from below the minimum miscibility pressure to well above. This work is being analyzed and will be presented at the SPE International Symposium on Oilfield Chemistry to be held in San Antonio 14-17 February 1995.

Reservoir Simulation Studies

During this quarter we have continued our focus on the adequacy of foam features that were previously incorporated into the reservoir simulators UTCOMP and MASTER. Sensitivity analysis on a number of foam parameters have been performed on a three-dimensional, quarter of a five-spot pattern model. It was found that the limiting gas saturation for foam generation has a significant effect on the response time of production. The effect of the limiting gas saturation will continue to be examined both numerically and experimentally. The production history from some of the tests have shown behavior similar to the response of the EVGSAU field pilot.

A new multiphase flash calculation algorithm, which is more efficient and robust than the standard hybrid algorithm, has been developed. In addition, an algorithm has been developed to improve the solution convergence in critical and three-phase regions. Currently, tests are being run at different conditions to assess the validity and applicability of the phase equilibrium calculation algorithms.

TASK 3 - LOW IFT PROCESSES AND GAS INJECTION IN FRACTURED RESERVOIRS

Construction of the pendant drop apparatus is in the final stages. We expect the first pressure tests to commence in the coming quarter. We also intend to devote the upcoming quarter on developing the hardware and software for drop digitization and data analysis.

While awaiting construction, two papers are nearing completion, which will 1) provide a theoretical basis for use of the Parachor Method and 2) outline an application of this method for calculation of multicomponent crude oil IFTs. We have assimilated all the measured data in the literature and determined that the method proposed as a result of our research is the most accurate method for calculating IFTs of complicated crude oil systems.

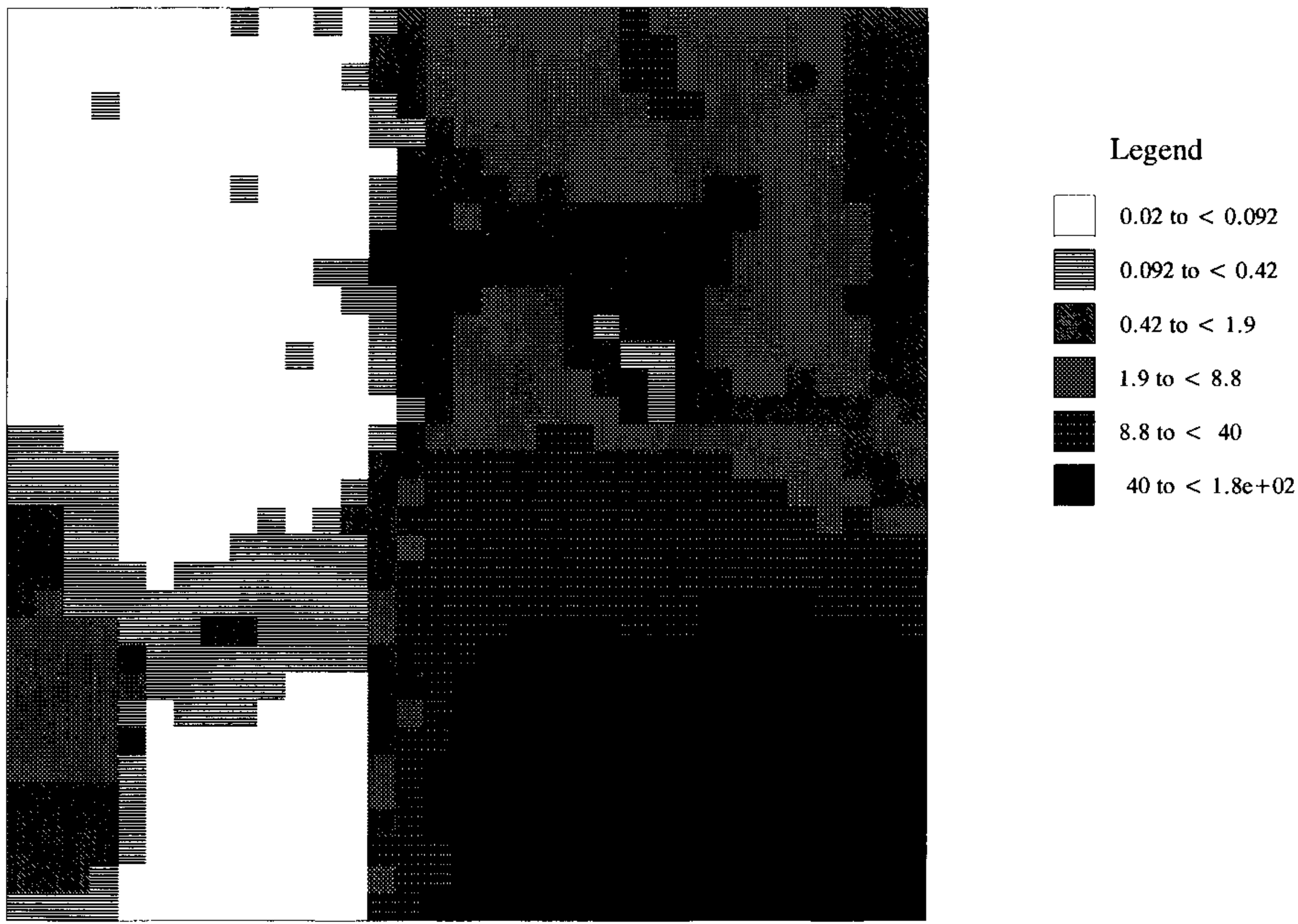
The lack of reservoir gas/oil and CO_2/oil data in the literature, however, has not allowed complete verification of the accuracy for the method proposed. The measurements that will be conducted with our new apparatus will further clarify reservoir IFT calculations, especially for systems that contain water.

REFERENCES

Chang, S-H. and Grigg, R.B.: "Laboratory Flow Tests used to Determine Reservoir Simulator Foam Parameters for EVGSAU CO_2 Foam Pilot," paper SPE #27675 presented at the 1994 SPE Permian Basin Oil and Gas Recovery Conference, Midland, March 16-18, 1994.

Lansangan, R.M. and Smith, J.L.: "Viscosity, Density, and Composition Measurements of CO_2/West Texas Oil Systems," *SPE Reservoir Engineering* (Aug. 1993) 175-182.

Fig. 1. TX 1B


Legend
0.02 to < 0.092
0.092 to < 0.42
0.42 to < 1.9
1.9 to < 8.8
8.8 to < 40
40 to < 1.8e+02